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Species Profiles: Life Histories and Environmental Requirements of Coastal Fishes and Invertebrates (Pacific Northwest)

PACIFIC OYSTER

Fish and Wildlife Service
U.S. Department of the Interior

Coastal Ecology Group
Waterways Experiment Station
U.S. Army Corps of Engineers

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of Coastal Fishes and Invertebrates (Pacific Northwest)

PACIFIC OYSTER

by

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PREFACE

This species profile is one of a series on coastal aquatic organisms, principally fish, of sport, commercial, or ecological importance. The profiles are designed to provide coastal managers, engineers, and biologists with a brief comprehensive sketch of the biological characteristics and environmental requirements of the species and to describe how populations of the species may be expected to react to environmental changes caused by coastal development. Each profile has sections on taxonomy, life history, ecological role, environmental requirements, and economic importance, if applicable. A three-ring binder is used for this series so that new profiles can be added as they are prepared. This project is jointly planned and financed by the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service.

Permission was obtained from the Canada Department of Fisheries and Oceans to use copyrighted material from Pacific Oyster Culture in British Columbia by D.B. Quayle (1969).

Suggestions or questions regarding this report should be directed to one of the following addresses.

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Slidell, LA 70458

or

U.S. Army Engineer Waterways Experiment Station
Attention: WESER-C
Post Office Box 631
Vicksburg, MS 39180

CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
meters (m)	0.5468	fathoms
kilometers (km)	0.6214	statute miles
kilometers (km)	0.5396	nautical miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.968	British thermal units
Celsius degrees (°C)	1.8(°C) + 32	Fahrenheit degrees

U.S. Customary to Metric

inches	25.40	millimeters
inches	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
statute miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
square miles (mi^2)	2.590	square kilometers
acres	0.4047	hectares
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet	1233.0	cubic meters
ounces (oz)	28350.0	milligrams
ounces (oz)	28.35	grams
pounds (lb)	0.4536	kilograms
pounds (lb)	0.00045	metric tons
short tons (ton)	0.9072	metric tons
British thermal units (Btu)	0.2520	kilocalories
Fahrenheit degrees (°F)	0.5556 (°F - 32)	Celsius degrees

CONTENTS

	Page
PREFACE	iii
CONVERSION TABLE	iv
ACKNOWLEDGMENTS	vi
NOMENCLATURE/TAXONOMY/RANGE	1
MORPHOLOGY AND IDENTIFICATION AIDS	1
REASON FOR INCLUSION IN SERIES	4
LIFE HISTORY	4
Reproductive Physiology	5
Spawning	5
Eggs	5
Larvae	5
Adults	6
GROWTH CHARACTERISTICS	7
THE FISHERY	8
Economic Status	8
Farming	10
ECOLOGICAL ROLE	12
Feeding Behavior	12
Summer Mortality	13
Predators	13
Parasites	15
Disease	15
Red Tide	15
ENVIRONMENTAL REQUIREMENTS	17
Temperature	17
Salinity	18
Siltation and Substrate	19
Water Circulation	19
Pollution	20
LITERATURE CITED	23

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Figure 1. Pacific oyster (Crassostrea gigas), showing external anatomy of shell valves.

PACIFIC OYSTER

NOMENCLATURE/TAXONOMY/RANGE

Scientific name . . . . . Crassostrea gigas (Thunberg)
Preferred common name . . . . Pacific oyster (Figure 1)
Other common names . . . Giant oyster, Japanese oyster, Giant Pacific oyster
Class . . . . . Bivalvia
Order . . . . . .Anisomyaria
Family . . . . . Ostreidae

Geographic Range: Morro Bay, California, to northern British Columbia; Japan (Quayle 1960; Fitch 1953). Quayle (1969a) reported that breeding occurs naturally only between Willapa Harbour (lat. 46° N.) and Pendrell Sound (lat. 50° N.). Consistent breeding occurs only in Dabob and Quilcene Bays in Washington and Pendrell Sound and Pipestem Inlet in British Columbia; breeding is rare or sporadic in other locations. Since the Pacific oyster has been moved into all the potential oyster growing areas in Washington, the species is at or near its geographical breeding limit (Quayle 1960). Major areas of commercial and recreational harvest of Pacific oysters are shown in Figure 2.

MORPHOLOGY AND IDENTIFICATION AIDS

The shell is extremely rough, extensively fluted, and laminated. The lower valve is deeply cupped and the upper valve is generally flat. The shells are usually whitish with many purple streaks and spots radiating away from the umbo. The shape of the shell varies with the environment (see Growth section). The interior of the shell is white, with a single muscle scar that is sometimes dark, but never purple or black. Maximum length is 10 inches, but normally length is 4-6 inches. Differs from Crassostrea virginica in never having a purple or black muscle scar, and from Ostrea lurida in its

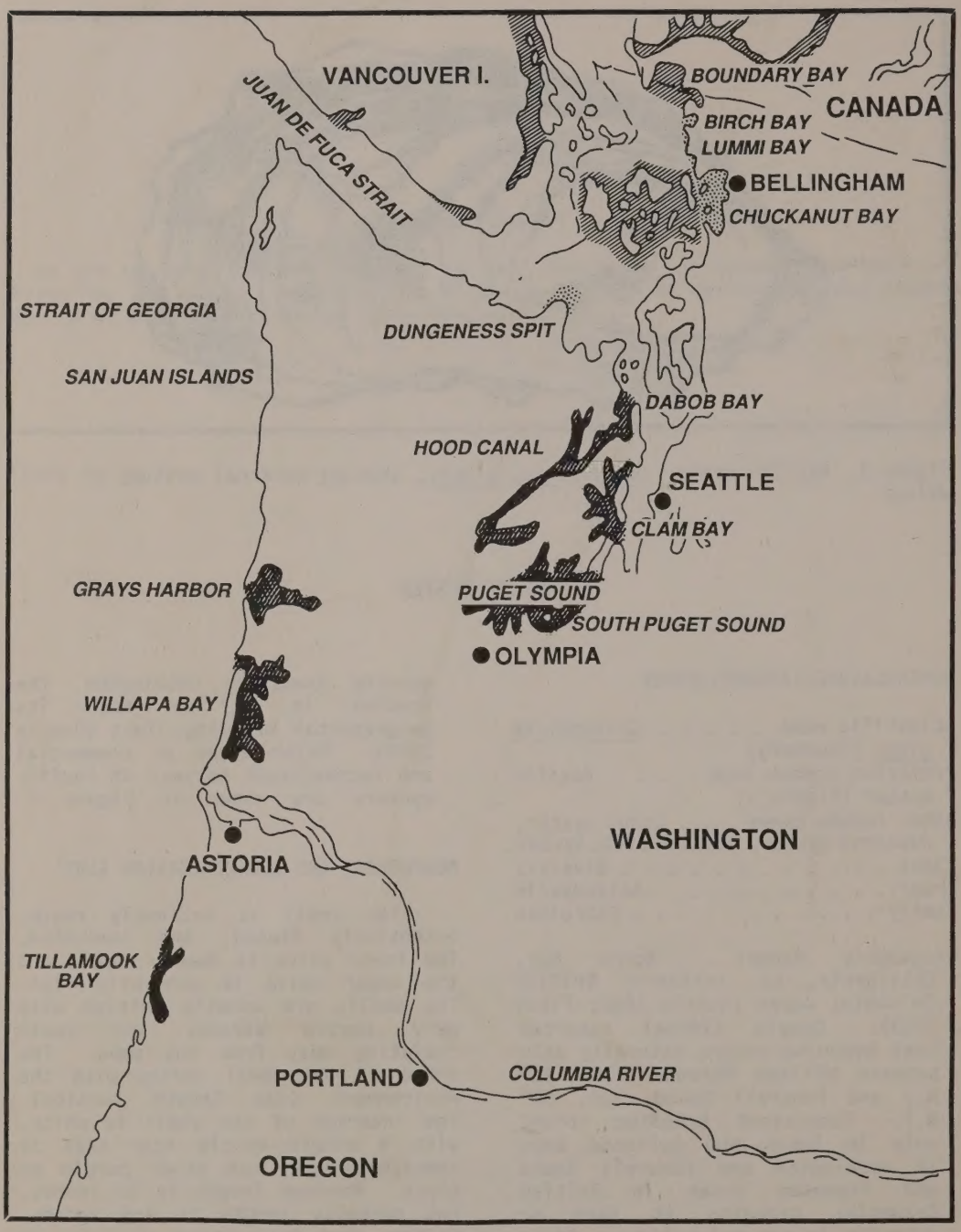
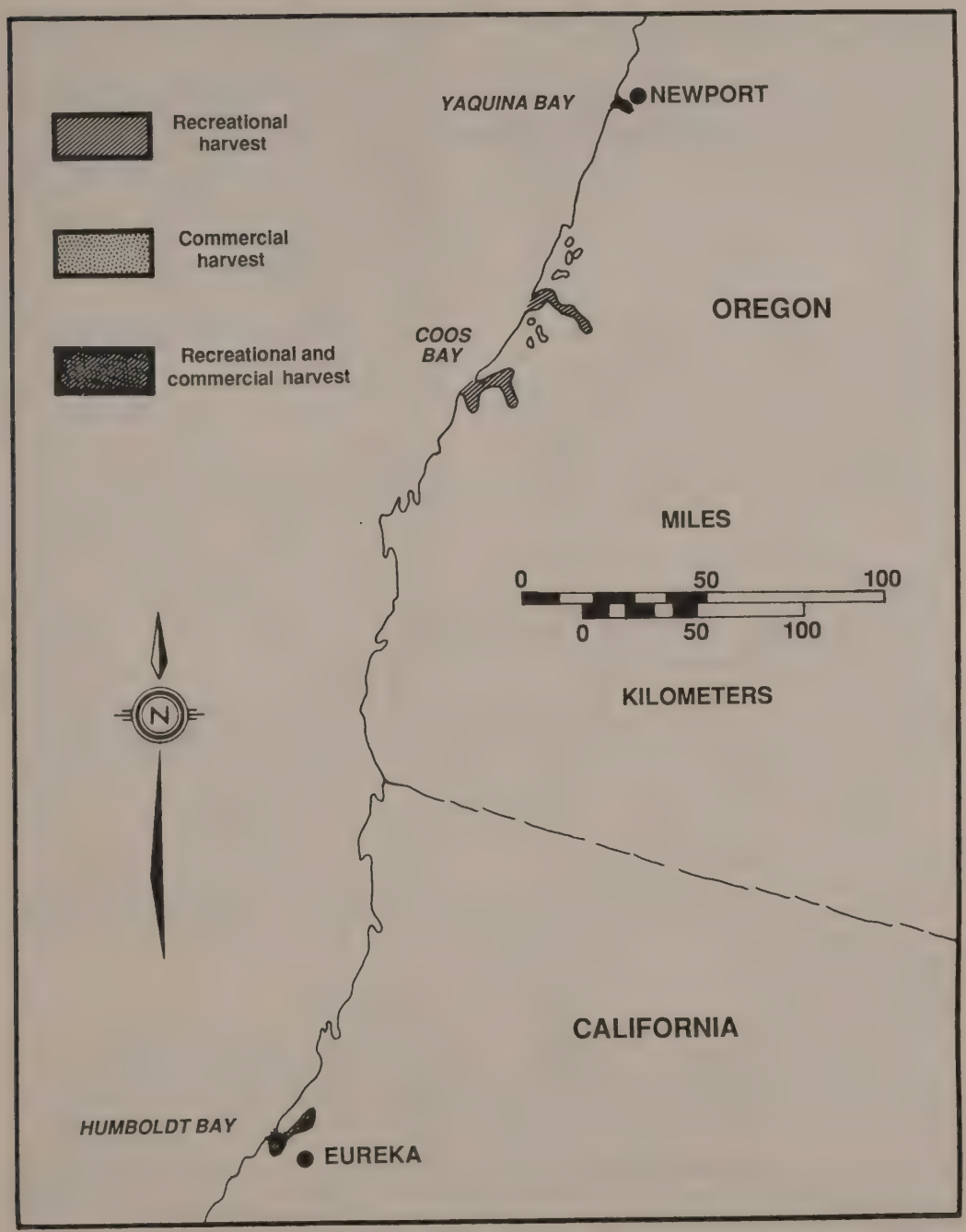


Figure 2. Geographic distribution of the Pacific oyster in the Pacific Northwest, showing major areas of harvest, commercial and recreational.


Recreational harvest
Commercial harvest
Recreational and commercial harvest
YAQUINA BAY
NEWPORT
OREGON
COOS BAY
MILES
0
50
100
0
50
100
KILOMETERS
N
CALIFORNIA
HUMBOLDT BAY
EUREKA

extremely large size and heavy shell. In addition, the inside of an O. lurida shell is iridescent green. For a comparison of C. gigas, C. virginica, and O. lurida see Table 1. Detailed descriptions of oyster anatomy have been published (Galtsoff 1964; Quayle 1969a).

REASON FOR INCLUSION IN SERIES

The commercial fishery for the Pacific oyster has grown rapidly since its introduction from Japan to the western coast of the United States in 1903 (Glude and Chew 1982). The United States now consumes almost 60% of the world's total oyster production. The Pacific oyster is a dominant shellfish in a growing United States aquaculture industry along the Pacific Coast because of its large size, marketability, and the ease of production in suitable areas (Glude and Chew 1982). Approximately 60%-70% of Pacific oyster production is marketed in the Pacific Coast States, but markets outside the region have been developed (Glude and Chew 1982). Washington State leads all other Pacific Coast States combined by a large margin in the production of Pacific oysters (Chew 1983; 1984), which comprise about 25% of all shellfish landings in Washington State.

LIFE HISTORY

The basic life histories of the Pacific oyster (C. gigas) and the Eastern oyster (C. virginica) are similar.

Table 1. Characteristics of the oyster species found in British Columbia, Oregon, and Washington (adapted from Quayle 1969a).

	Oysters		
Characteristic	Native or Olympia (Ostrea lurida)	American or Eastern (Crassostrea virginica)	Pacific or Japanese (Crassostrea gigas)
Promyal chamber	Lacking	Present	Present
Adductor muscle scar:			
Color	Uncolored	Dark purple or brown	Mauve or white
Outline	Clearly outlined	Clearly Outlined	Not clearly outlined
Length (inches)	2 in	3-4 in	4-6 in
Concentric growth	Indistinct	Flat but clear	Projecting with flutings
Radial grooves	Not apparent	Barely apparent	Generally deep
Inside shell color	Green iridescent	White	White
Outside shell color	Gray-green with dark purple	Yellow brown	Gray with purple

Reproductive Physiology

Pacific oysters are protandrous hermaphrodites (Fretter and Graham 1964; Katkansky and Sparks 1966); they change sex, but their timing is erratic and seasonal. The young are functionally male during their first spawning, while about half remain males for their second spawning. The adults function as separate male or female animals in any given reproductive season, but a change of sex from male to female often occurs at some point in life (Katkansky and Sparks 1966). Sexual maturity is reached during the first year.

Spawning

Pacific oysters spawn annually in certain coastal waters of British Columbia (Quayle 1969a) when the water temperature is approximately 19.5°C. Once the spawning temperature has been reached, which is usually sometime in July or August, spawning is synchronous (Quayle 1969a).

Under natural conditions, simultaneous release of sperm and eggs into the water column is attained through mutual stimulation (Galtsoff 1964). The gametogenesis and histology of developing ova and sperm in C. gigas have been described (Katkansky and Sparks 1966; Quayle 1969a), as have those aspects in C. virginica (Galtsoff 1964; Kennedy and Battle 1964).

Eggs

Oysters are highly prolific. An average market-sized female oyster (3 inches long) can produce 50-100 million eggs in a single spawning (Quayle 1969a). Fertilized eggs of the Pacific oyster are spherical, and 45-62 µm in diameter. The egg is multilayered, with membranes that divide the jellylike outer coat from the small nucleus (Galtsoff 1964). The germinal vesicle is eccentrically located within the nucleolus.

Temperature plays a major role in the development of the fertilized oyster egg. A decrease of 2°C (from 24.5°C to 22.5°C) doubled the time required for the formation of the trochophore larvae (Galstoff 1964). Fertilized eggs reached the veliger stage in 72 hours at 14°C, and in 28 hours at 22°C (Loosanoff and Davis 1963).

Larvae

If prevailing conditions are favorable, 90%-95% of the fertilized eggs develop to the shelled veliger stage within 48 hours. The resulting pelagic larvae are planktotrophic, feeding on phytoplankton and growing over a period of 2 to 3 weeks (Kennedy and Breisch 1981).

As the larvae grow, their length continues to be 5-10 µm greater than their width. This condition persists until the larvae reach about 90 µm. At 100 µm, the length and the width are equal, but beyond 125 µm the width grows faster than the length, forming what is generally observed as an oyster larva (Loosanoff 1965; Loosanoff et al. 1966). Complete length and width relationships in C. gigas, as well as other bivalves are given by Loosanoff et al. (1966).

Growth of the free-swimming larvae depends on many factors; the length of the larval period is dependent on the water temperature. Temperatures must be 20°C or greater for at least three weeks for near optimal growth (Magoon and Vining 1981). Although larvae can survive slightly lower water temperatures, this prolongs their development and increases their exposure to pelagic predators (Kennedy and Breisch 1981).

Detailed descriptions of the anatomical development of C. virginica larvae from first cleavage to setting are provided by Galtsoff (1964). Photographs of C. gigas larval development at various sizes is presented by

Loosanoff et al. (1966). Additional information concerning the effects of temperature, salinity, and turbidity on eggs and larvae is presented in Loosanoff (1965).

The primary determinant of distribution of a pelagic planktonic species that eventually settles on the bottom is the prevalent water currents during the critical free-swimming stages of the larva (Westley 1968; Quayle 1969a). Dispersal can be quite broad, but only areas with suitable habitat sustain populations of oysters. When the oyster larvae reach a length of about 0.30 mm, their free swimming existence ends and they attach to the bottom or a hard substrate as spat (Quayle 1969a)

An eyespot develops when the larva shell length reaches 250-175 µm. This "eye" remains throughout the free-swimming stage, and may serve as a defense mechanism (Loosanoff 1965). Developing in conjunction with the eyespot is a foot containing a byssal gland (Loosanoff 1965). This foot is extended when the larva is ready to set. The foot will attach to any solid surface with which it comes into contact. When contact is made, the larva crawls onto the surface and, if it is suitable, attaches by the left valve (Kennedy and Breisch 1981). At this point, oysters are no longer free-swimming and are called spat. Lutz et al. (1970) found that the larvae can be stimulated to set by temperature manipulation. Other factors critical to setting include the presence of oyster shells or other suitable substrate (Crips 1967), sufficient light (Ritchie and Menzel 1969), and surface irregularities on the substrate (Galtsoff 1964). The presence of a water-borne "gregarious factor," a substance released by newly set C. virginica spat that apparently attracts other spat, was demonstrated by Hidu et al. 1978.

This metamorphosis from free-swimming larvae to spat is accompanied by some marked morphological changes, such as the disappearance of the velum and foot as well as the anterior adductor muscle, and the development of an enlarged set of gills (Loosanoff 1965; Quayle 1969a). After setting, the juvenile oyster is a sessile animal, which will grow to adult size and die in the area of setting, unable to voluntarily move around. Kennedy and Breisch (1981) provide a detailed description of the predators of juvenile oysters. Loosanoff (1965) details the various diseases common to juvenile oysters.

Adults

There are contrasting reports concerning the effect of population densities on oyster growth. Studies of O. edulis have found shell growth is unaffected by contact with adjacent oysters, but the volume of meat is reduced (Cole and Waugh 1959; Sheldon 1968), which may be due to competition or some other variable. The problem of too many oysters and too little food is a major limiting factor in any high-density area.

The mechanical process of filter feeding in adult oysters is well documented (Nelson 1938; Korringa 1952; Menzel 1955; Owen 1974). During feeding, various particles are sorted according to size by mucous secretions. Bernard (1974) found that the amount of mucus secreted depends on the degree of mucous gland stimulation by foreign particles. Larger particles evoke copious mucous secretion, while small particles evoke less. This sorting of food particles takes place on the ciliated labial palps (Kennedy and Breisch 1981). The anatomy and physiology of the palps, which are actively involved in the feeding process was described in detail (Yonge 1960; Galtsoff 1964). The histological anatomy of the entire digestive tract has been described in C. virginica by Shaw and Battle (1957).

GROWTH CHARACTERISTICS

Larval growth seems to be directly related to water temperature with faster growth at higher temperatures (Quayle 1969a). In the temperature range 64°F to 75°F, larvae of the Pacific oyster in British Columbia will grow from 75 µm in length to about 300 µm during the period from mid-July to mid-August (Quayle 1969a). Loosanoff et al. (1966) showed that the shapes and therefore the relationship of width to length of larvae varies at different growth stages. Langton and McKay (1974, 1976) discussed the effects of feeding variations on the growth of C. gigas spat.

Oyster size in Washington State after 2 years of growth is directly related to the initial planting size and the month planted, with earlier planting (about April) producing the largest oysters (Scholz and Westley 1971a, 1971b). Growth of tray-reared seed oysters (seed oysters are already set but small) and ground-reared seed oysters was the same in Washington, although tray-reared seed oysters had twice the survival rate (Scholz 1973). In Alaska, mortality was 3% in raft-grown oyster spat compared to 63% mortality in nearby bottom-planted spat (Yancey 1966). Crowded spat grow more slowly during their initial 6 months after planting (Scholz 1974).

Seed oysters should reach a length of 4 to 5 cm during their first year. Oysters generally grow more rapidly when they are young with a reduction in growth rate when they are 4 or 5 years of age (Quayle 1969a).

Growth in oysters varies widely with tidal height, growing area, and environmental conditions. Oyster growth can be measured by increases in shell size or body size. As a general rule, growth is faster as water temperature increases (Loosanoff 1965). Oysters have been known to live as long as 40 years, with longer life attained at the more northern latitudes.

Shell deposition is controlled by the activity of the mantle surface (Galtsoff 1964; Quayle 1969a). Shell growth occurs mainly in summer when elevated water temperatures result in increased food supply and increased metabolism, using the available calcium for shell deposition (Quayle 1969a). Starting in the fall, as water temperatures decrease, growth drops greatly, with only minor shell growth occurring during the winter (Sparks and Chew 1961).

Oysters exhibit compensatory growth, growing wider when lengthwise growth is physically retarded, or vice versa. Therefore, shell size as an indicator of growth is given as the product of length and width (Katkansky et al. 1967). Oyster growth can appear to be affected by handling, due to the loss of fragile extensions of new shell growth (Sparks and Chew 1961), but this does not seem to affect oyster survival. Fouling organisms associated with oysters sometimes have a significantly negative effect on growth, even causing it to cease (Michael and Chew 1976).

The shape of the oyster depends greatly on the type of surface upon which it is grown. If it is attached to a solid object, the left, or lower valve follows the contour of that object (Quayle 1969a). Oysters grow long and narrow on soft mud or in clusters, and are round and deeply cupped, with extensive fluting of the shell, when grown on a hard surface, such as gravel (Quayle 1969a).

Weighing an oyster by finding the weight of the water it displaces essentially provides the weight of the shell since the specific gravity of oyster meat is very near to that of water. A time series of such measurements provides a record of shell growth (Quayle 1969a).

The basic measure of oyster productivity is volume (Quayle 1969a). The ratio of whole volume to shell volume indicates the volume of meat an oyster can produce for its size. The length to volume ratio will change in Pacific oysters depending upon the age of the animals (Figure 3). These volume relationships have important implications to oyster growers.

The market value of oyster meat depends on a high condition index, which is defined as the amount of stored glycogen, lipid, and germinal tissue of an oyster in proportion to its internal shell volume (Kennedy and Breisch 1981). Westley (1964) found that a bushel of C. gigas in prime condition yielded one gallon of shucked meats, whereas a bushel of oysters in poor condition yielded only half a gallon. The condition index of an oyster depends on its feeding behavior, the nutritional value of its food, and its reproductive state (Korringa 1952). Oysters that are ready to spawn, or that fail to spawn because of low water temperatures are not considered to be of good marketable quality (Quayle 1969a), even though they may have a high condition index.

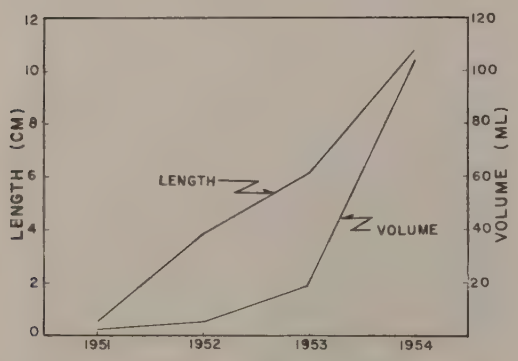


Figure 3. Length and volume increases of Pacific oysters followed over 4 consecutive years in British Columbia (after Quayle 1969a, Pacific Oyster Culture in British Columbia, Fisheries Research Board of Canada, with permission of the Department of Fisheries and Oceans).

THE FISHERY

Economic Status

The United States is the largest oyster producing and consuming nation in the world. The United States annually produces 50 million pounds of oyster meats and imports over 20 million pounds, thereby consuming approximately 56% of the world's total annual production (Glude and Chew 1982).

Washington State is the largest producer of oysters on the Pacific Coast (Chew 1983, 1984). The Washington State production of approximately 5 million pounds of oyster meat is about 5 times greater than the combined production of British Columbia, Oregon, and California (Figure 4). The annual oyster harvest in Washington State amounts to 33% of the total shellfish weight harvested and 26% of the landed dollar value at $3.8 million out of $14.6 million in 1982 (Washington State Department of Fisheries 1983). This comprises the largest landing percentage and dollar value for any commercial shellfish species harvested in Washington State (Figure 5). Peak oyster production on the Pacific Coast was from 1954-56, when harvests exceeded 10 million pounds of meats (Glude and Chew 1982). Since 1965, annual production has been 4 to 7 million pounds of meats in the coastal states of Washington, Oregon, and California. The decrease in production after 1956 is attributable to the importation of lower priced canned oysters from Japan and Korea (Glude and Chew 1982). Improper seeding of oyster beds and increased pollution have caused decreases in some areas. Limited shelf life and marketing problems restrict the market for refrigerated fresh oyster meats (Magoon and Vining 1981).

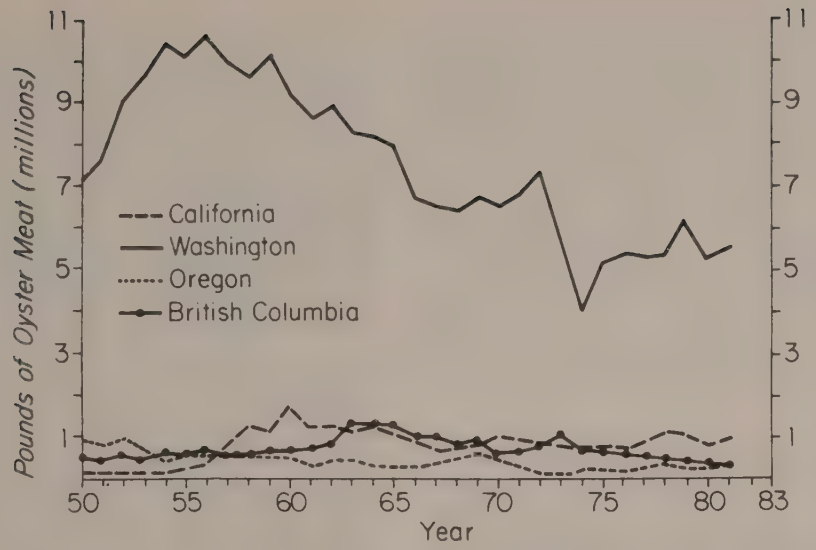


Figure 4. Commercial production of oysters in California, Oregon, Washington and British Columbia (after Chew 1983).

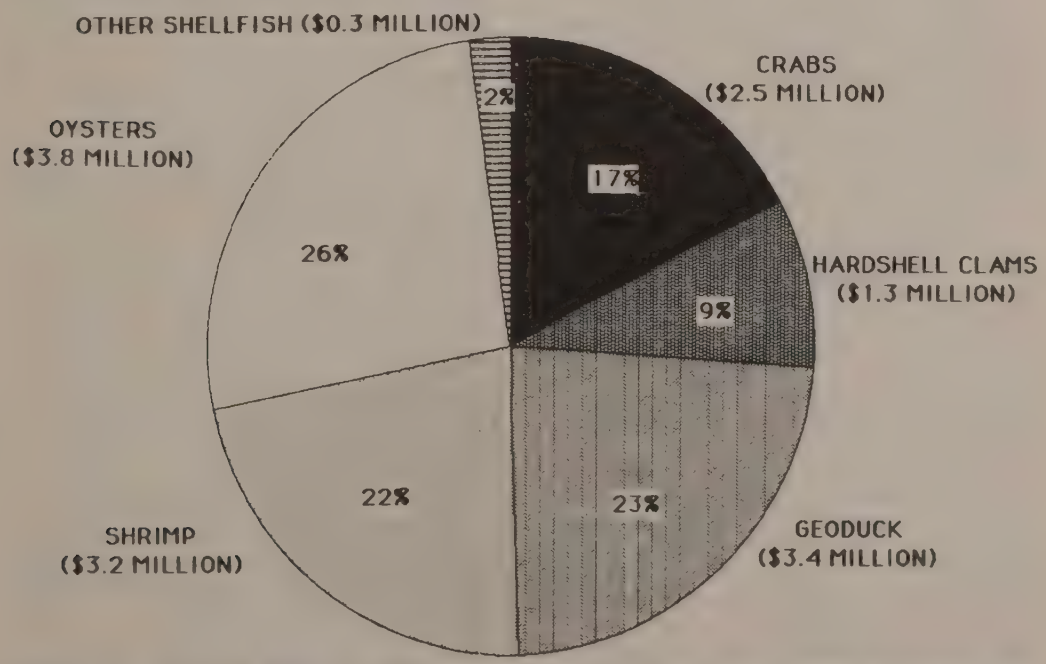


Figure 5. Oysters made up 26% of the $14.6 million total landed value of all Washington State shellfish in 1982 (modified from Washington State Department of Fisheries 1983).

Approximately 60%-70% of C. gigas production is marketed in the Pacific Coast states. Nearly all the Pacific Coast production of oysters is shucked and sold as fresh or frozen product. Only 5%-10% is sold in the shell for shucking by the consumer for the half-shell trade. This demand is especially high for oysters grown off the bottom or on hard substrates, since these have a reportedly milder flavor than oysters raised on muddy substrates (Glude and Chew 1982). This type of oyster commands a premium price.

Farming

There is potential for restoring West Coast oyster production to 10 million pounds by applying present bottom culture techniques in underutilized areas (Glude and Chew 1982). There is a considerable amount of underutilized area available (Table 2). With increased consumer demand, the availability of adequate oyster seed, and the application of off-bottom culture techniques, future production of Pacific oysters could exceed 20 million pounds of meats per year (Glude and Chew 1982).

The Pacific Northwest waters are generally too cool for C. gigas adults to spawn successfully or for their larvae to settle in quantities appreciable for commercial use (Korringa 1976). Exceptions to this are Dabob Bay and Quilcene Bay in Washington, where yearly spatfall averages about 25 per shell of cultch, while in Pendrell Sound in British Columbia, commercial sets of over 1,000 spat per shell are not uncommon (Korringa 1976; Chew, pers. comm.). Both areas are relatively protected; summer water temperatures regularly exceed 20°C and where hydrographic features facilitate oyster larval retention (Quayle 1969a; Korringa 1976). Hydrographic conditions occasionally allow commercial collection of naturally produced oyster spat in Willapa Bay, Washington, or in Ladysmith Harbour, British Columbia, but in most years the spat do not settle in commercial quantities (Quayle 1969a; Korringa 1976). Commercial sets may occur irregularly in about 6 out of 10 years in Willapa Bay with 10 spat per shell considered a good set (Chew, pers. comm.). Pacific oysters are cultured to the spat stage and transplanted to many areas shown in Figure 2 for rearing to adult size and subsequent harvest.

Table 2. Tidelands in acres usable for oyster culture in Washington, Oregon and California.

State	Total Area	Total area in Production
Washington	42,000	16,000
Oregon	4,000	1,350
California	17,150	2,120
TOTAL	63,150	19,470

In warmer summers, these natural sources supply as much as two-thirds of the seed needed for the Pacific Northwest oyster aquaculture industry (Washington State Department of Fisheries 1983). Until about 1982, oyster seed was imported from Japan, which historically provided the bulk of the industrial seed demanded (Glude and Chew 1982). Today, commercial hatcheries along the Pacific Coast are successfully producing oyster seed at competitive prices (Glude and Chew 1982). One hatchery technique involves shipping eyed oyster larvae to growers (Breese 1979; Chew 1983). The larvae are allowed to set and form spat on the grower's cultch.

Oyster seed, attached to cultch (usually shucked oyster shells), is generally "implanted" directly onto growing beds, or sometimes onto gravel

nursery beds for the first year or two (Glude and Chew 1982). Much of the Pacific oyster culture in Washington and British Columbia is done on intertidal beds with gravel, sand, or mud bottoms. At relatively high tides, less siltation and fewer predators allow better oyster seed survival (Quayle 1969a), with survival improved from 22% at the zero tidal level to 61% at a point 6 ft above zero tidal level.

During the growing period, clusters of oysters need to be broken up, separated, and thinned. Oysters are often transferred after 1 or 2 years to better growing beds to improve their condition (Korringa 1976). Best growth was reported at the zero tide level, while fattening was greatest at the 3- to 4-ft mark (Quayle 1969a). The selection of ground suitable for oyster culture is based mainly on three factors: tidal level, bottom consistency, and protection from wave action (Quayle 1969a).

Growth to market size varies with latitude, ranging from less than 2 years in California, to 2 to 4 years in Oregon and southern Washington, and 4 to 6 years in northern Washington, British Columbia and Alaska (Glude and Chew 1982). Oysters are harvested either by hand at low tide or by various dredges at high tide (Glude and Chew 1982). Bottom culture is used by most Washington commercial oyster growers because it is most economical and requires a minimum of labor (Magoon and Vining 1981).

Stake culture techniques are used to grow C. gigas on the intertidal beds at Coos Bay, Oregon, and Tomales Bay, California, where the bottom sediments are generally too soft for culture. Wooden stakes 4 to 5 ft long are pushed into the substrate at 3 ft intervals, and several large oyster shells with spat are attached to them (Glude and Chew 1982; Magoon and Vining 1981). The additional labor cost of stake culture is offset by the accelerated growth and excellent quality of the oysters (Glude and Chew 1982).

In Tomales and Drakes Bay, in California, oyster shells with attached spat are suspended from long fences or racks 4-5 ft high, located in the lower part of the intertidal zone. This method not only increases their growth rate, but also protects them from predatory bat rays, Holorhinus californicus (Glude and Chew 1982).

Off-bottom oyster culture, using rafts, racks, or stakes, has been tried in various locations along the Pacific Coast. Raft culture is used at Yaquina Bay, Oregon, because suitable intertidal beds are lacking and protected estuarine waters are available (Glude and Chew 1982).

Cultch, with oyster spat attached, are strung on rope or wire and suspended from log rafts (Magoon and Vining 1981). This method of oyster culture has three advantages over beach culture. First, growth to marketable size is reduced by 1 to almost 2 years (Quayle 1969a), perhaps because oysters are immersed continuously and thus have more opportunity to feed (Pereyra 1961; Magoon and Vining 1981). Second, at all times of the year, oysters grown by raft culture are fatter than those grown on beaches only a few hundred yards away (Quayle 1969a). Third, mortality caused by siltation or predation does not occur (Quayle 1969a).

Quayle (1971) recommended only one growing season by raft culture, claiming relatively little additional growth in the second year, with significant fouling. Weller (1978) found good potential for commercial raft culture of Pacific oysters near Squaxin Island in southern Puget Sound and reported a significant increase in production during the second year of growth.

At this time, off-bottom cultures account for a relatively small proportion of West Coast oyster production due to a low profit margin associated with high costs of production (Glude and Chew 1982). In the future, these methods may have greater promise, when suitable intertidal beds are fully utilized and the price and demand for Pacific oysters increase.

ECOLOGICAL ROLE

Feeding Behavior

Oysters feed on planktonic organisms which are filtered by the gills, entrapped, and bound in mucus. Strings of mucus then carry the particulate matter to the labial palps, where it is sorted and either passed into the mouth or rejected as pseudofeces (Korringa 1976; Kennedy and Breish 1981). Pseudofeces are filtered materials which have not been passed through the digestive system. Food is carried by the mucous strings to the alimentary canal, and sorted again by the caecum (Menzel 1955). Oysters use an organ unique to bivalves and gastropods called a crystalline style to assist in the digestion process (Galtsoff 1964; Quayle 1969a).

Some oysters can filter particles smaller than 2 µm, but retention efficiency increases with larger particles 3-10 µm (Kusuki 1977a, 1977b). Oysters seem to differentially select particles to consume or reject, since stomach contents do not fully represent the phytoplankton composition to which oysters are exposed (Grave 1916; Morse 1944).

Oysters ingest bacteria, protozoa, a wide variety of phytoplankton, larval forms of other invertebrate animals, inanimate organic material called detritus, and some inorganic material (Quayle 1969a). Little is known of what portion of the various ingested items is actually usable food, or of what nutritional value they are to oysters. Some oyster growers associate spring fattening of oysters with the usual spring bloom of diatoms, caused by an ideal combination of light, temperature, and nutrients (Quayle 1969a).

It is still unclear whether oysters feed and digest food continuously or in daily patterns. Morton (1977) postulated that intertidal populations of C. gigas feed discontinuously, corresponding to tidal cycles. Oysters cultured by off-bottom techniques show increased growth, perhaps as a result of continuous feeding (Pereyra 1961, Quayle 1969a). However, Langton and McKay (1974) reported consistently higher growth in spat subjected to a discontinuous feeding regime. Feeding is closely tied to the rate of water transport through an oyster, which in turn is affected by such environmental conditions as water salinity, water temperature, water circulation, pollution, and suspended silt and by biological conditions such as competition and food concentration (Quayle 1969a).

Loosanoff and Engle (1947) found that when algal concentrations were high, pumping rates decreased and oysters often became sluggish in response to stimuli. They hypothesized that this laboratory observation was caused either by toxic metabolites excreted from dense algal concentrations or by the highly concentrated level of nutrients used to culture the algae. Bacterial populations can be associated with large numbers of algal cultures, and together with high temperatures may cause oyster mortality (Lipovsky and Chew 1973, 1974).

Field studies in Washington showed areas with unstratified waters having moderate to rapid volume exchange, sustained phytoplankton production, and high levels of nitrate and phosphate nutrients produced oysters in good condition (Westley 1968). Under laboratory conditions,

larval setting of Pacific oysters was reduced by poor nutrition and algal concentrations of less than 5,000 cells/ml (Lund 1971). Optimal laboratory growth rate for oyster larvae occurred at an algal inflow density of 20,000 cells/ml (Malouf 1971). The rate of food consumption increased as algal densities decreased or as water temperatures increased from 10 to 24°C. Greater feeding rates do not necessarily correspond to proportionately greater larval growth, for some food was incompletely assimilated or rejected as pseudofeces (Malouf and Breese 1977).

Summer Mortality

Throughout the late 1960's and 1970's mass mortalities in Pacific oysters of up to 65% have occurred during warmer than usual summers in Washington, California, and at Boundry Bay in British Columbia (Quayle 1969a; Beattie 1978; Beattie et al. 1980). Mortalities have generally occurred during late summer when water temperatures approached or exceeded 20°C among oyster stocks that were 2 years or older, had relatively high condition indices, and were located in areas of high nutrient levels (Perdue et al. 1981). Glude (1975) noted that this condition in the oysters was accompanied by degenerative necrosis of the digestive diverticulum. The largest oysters, exhibiting heavy gonadal development, comprised the greatest proportion of the mortalities (Glude 1975). Although mortality seemed selective against females, male oysters died also (Perdue et al. 1981). However, Glude (1975) did not observe this sex difference.

Lipovsky and Chew (1972) simulated summer mortality in the laboratory and suggested that a Vibrio bacterium was involved. Although the cause of mass oyster mortality has not been positively identified, Vibrio were implicated as facultative pathogens (Grischkowsky and Liston 1974; Lipp et al. 1975). Brown (1977) found that only a small number of Vibrio strains are virulent, and the ability of bacteria to cause disease depends greatly on their ability to pass the oyster's defense mechanisms in large numbers. He found Vibrio anguillarum to be the organism most frequently isolated from oysters that died in the laboratory.

Environmental pressures, such as long periods of exposure to air, warm temperatures, or dinoflagellate blooms, may trigger mortality in oysters already in a stressed state (Beattie 1978). Beattie et al. (1978) found good potential for development of a strain of oysters resistant to laboratory-induced summer mortality. Experimentally selected, genetically resistant oysters were planted in Rocky Bay, Washington, and subsequently experienced summer mortality in 1978 that was lower than for the control oysters (Beattie et al. 1980). Variability in the carbohydrate cycle and gonadal development of selectively bred oysters indicated a possible genetic component to oyster response to environmental cues (Purdue et al. 1981).

Predators

Crabs and starfish can be serious predators on young and adult Pacific oysters in Oregon, Washington, and British Columbia (Quayle 1969a). In Puget Sound and the Strait of Georgia, oyster seed stocks also can be significantly reduced by the inadvertently imported Japanese oyster drill Ocinebra japonica and by the predatory flatworm Pseudostylochus ostreophagus (Quayle 1969a; Beattie 1982).

The Dungeness crab Cancer magister, the rock crab C. productus, and the graceful crab C. gracilis, chip and open young oysters and oyster seed with their claws (Quayle 1969a). Generally, crab predation is not a major problem, although few oyster beds escape damage completely. The most devastating effect is to the

young seed oysters. Crab predation can be controlled by keeping oyster seed off the bottom, or by a simple crab trapping program (Quayle 1969a; Magoon and Vining 1981).

The most serious oyster predators in British Columbia, particularly in subtidal cultures, are the sun star Pycnopodia helianthoides, the mottled star Evasterias troschelii, the ochre star Pisaster ochraceus, and the pink star Pisaster brevispinus (Quayle 1969a). A starfish can pull an oyster shell open by applying more than ten pounds pressure to the oyster shell with its suction-tipped tube feet. The evertible stomach is then forced into the narrow opening between the valves, and the victim is digested within its shell in less than 24 hours (Magoon and Vining 1981). Eight months after terminating a starfish removal program in Departure Bay, British Columbia adult oysters had suffered 70% mortality, and oyster seed 100% mortality (Quayle 1969a).

In intertidal areas, starfish can be controlled by removal or by applying a teaspoon of quick lime to their backs (Quayle 1969a). Chopping starfish up will generally result in more starfish, due to their amazing regenerative ablities. After an oyster bed has been cleared of starfish, it may become reinfested by free-swimmming starfish larvae during spring and summer. Young starfish up to 3 inches (75 mm) in diameter appear to be light shy. Starfish 12.5 mm in diameter attacked oyster spat, and those that were 125 mm could attack oysters of market size (Quayle 1969a).

The Japanese oyster drill is considered to be one of the most serious predators on Pacific oysters and also will attack a variety of molluscan bivalves (Chew and Eisler 1958). Accidentally introduced from Japan, the Japanese drill is now well-established along the Pacific coast and in the bays of Puget Sound (Chew 1960). The Japanese oyster drill is a snail that uses acid and its raspy tongue (radula) to drill a hole through the oyster's shell. It then uses the radula to tear out the meat (Quayle 1969a; Magoon and Vining 1981). This process is completed in 5-6 days on young oysters (Chew 1960). Oysters over 2 years old are relatively safe from this predation, due to the thickness of their shells (Magoon and Vining 1981). Under laboratory conditions, it was found that given a choice, Japanese oyster drills preferred Manila clams (Venerupis japonica), Olympic oysters (Ostrea lurida), and bay mussels (Mytilus edulis) to Pacific oysters (Chew and Eisler 1958; Chew 1960). In a subsequent study by Ellifrit (1971), drills showed no definite preference between Pacific oysters, bay mussels, native little-neck clams (Protothaca staminea), or barnacles (Balanus spp.). In some areas, the Japanese oyster drill can cause a 90% loss of oyster stocks (Glude and Chew 1982). The native drill, Thais lamellosa, although present on oyster beds, attacks barnacles, clams, and mussels rather than oysters (Quayle 1969a).

More than 50,000 Japanese drills were found per acre at Liberty Bay in the Hood Canal area of Washington (Lindsay 1961). The area became unsuitable for seed oysters, although half-grown and adult oysters could still be grown and fattened there. Gravel treated with orthodichlorobenzene and Sevin appeared to control drills in the intertidal area, by forming a permanent barrier around oyster seed beds (Lindsay 1961).

The Japanese oyster drill can be controlled somewhat by collecting its egg cases before the eggs hatch, and by careful oyster farming practices (Glude and Chew 1982). The Washington Department of Fisheries must be contacted before oysters or oyster shells are moved within the State, to help prevent the spread of Japanese drills (Magoon and Vining 1981). Inspection at the packing sites in Japan helped

prevent further importation of drills and other pests on seed oysters (Quayle 1969a).

In areas where Japanese oyster drills are already a problem, only oysters over 2 years of age should be planted. After the oysters are harvested, the beds should be cleaned as thoroughly as possible, the ground raked, and the debris taken ashore. Drills can also be buried by pulling drags over the area (Quayle 1969a).

Mud shrimp (Upogebia pugettensis), and ghost shrimp (Callianassa californiensis), cause serious damage to oyster beds (Quayle 1969a). They dig "U"-shaped burrows with two openings which retain water at low tide, making the beds too soft for oyster culture. The tremendous turnover of sediment by these animals results in the burial of bottom cultured oysters. The pesticide Sevin has been used controversially as a control agent in Washington for ghost shrimp.

Parasites

The parasitic copepod Mytilicola orientalis is a small bright red crustacean introduced to the West Coast with oysters imported from Japan. The maximum length of the organism is about 10 mm and it occurs in the small intestine of various molluscs (Quayle 1969a). Studies of M. orientalis in three areas along the Pacific Coast found that infestation was highest at Yaquina Bay, Oregon, intermediate at Humboldt Bay, California, and lowest at Oyster Bay, Washington (Chew et al. 1964). The parasite was found to be continuously reproductive throughout the year, although fewer egg carrying females were found during winter (Chew et al. 1964). High infestations did not appear to affect oyster growth (Chew et al. 1964), or survival (Katkansky et al. 1967). Infestation was associated with a lower condition of Pacific oysters, although it was not clear whether the copepod caused the poor condition or whether oysters in poor condition were more susceptible to copepod invasion (Chew et al. 1964). Extensive local tissue damage can occur in the gut of the oyster (Sparks 1962; Sindermann 1974).

Consumption of oysters infested with Mytilicola poses no human threat, but the presence of M. orientalis impairs the oyster's appearance (Katkansky et al. 1967).

Boring sponges (Cliona celata) and sea worms (Plydora ciliata), which weaken the shell by boring holes into it, have been serious pests to oysters grown in other parts of the world. Although both species occur in the Northwest, they have not been a problem there (Quayle 1969a).

Disease

Pacific oysters do not seem to be greatly affected by diseases, although occasional disease outbreaks have occurred (Quayle 1969a).

Focal necrosis, caused by an unidentified gram-positive bacterium, has been found in seed and market-sized oysters in Willapa Bay, Washington (Sindermann 1974). Gross disease signs include pale digestive glands, gaping, and sporadic mortalities. No treatment has been reported.

Bacillary necrosis, caused by Vibrio anguillarum, has been reported to affect Pacific oyster larvae (Beattie 1978), where larval motility decreases, followed by mortality. Sindermann (1974) suggests treatment by administering antibiotics, accompanied by improvements in the water quality and general sanitation to help prevent this disease.

Red Tide

Occasionally, environmental conditions encourage epidemic growth of various algae or planktonic organisms,

coloring the waters of affected bays dull orange to cherry red. Of particular concern are outbreaks of the microscopic dinoflagellate, Protogonyaulax catenella, which produces a highly virulent poison (Quayle 1969b). Gonyaulax catenella, along with several other members of the genus, have been recently transferred to the genus Protogonyaulax (Taylor 1979). Organisms in this group are difficult to separate taxonomically, with several types resembling P. catenella (Toriumi and Takano 1979). Filter-feeding shellfish do not seem to be affected by the poison, although they accumulate the toxin in their tissues (Quayle 1969b). Human consumption of the infected shellfish causes paralytic shellfish poisoning, a potentially lethal condition affecting the nervous system (Nishitani and Chew 1983).

Blooms of P. catenella occur along the Pacific Coast, from Alaska to central California (Quayle 1969b; Beattie 1982). The oyster market is not generally affected, since oysters are usually harvested in winter when paralytic shellfish poisoning is less likely to occur (Glude and Chew 1982). However, a number of people became ill after eating infected oysters in the Comox-Courtenay area along the east coast of Vancouver Island, British Columbia, in October 1957 (Quayle 1969b). Common edible marine bivalves that become highly toxic are littleneck clams (Protothaca staminea), Manila clams (V. japonica), butter clams (Saxidomus giganteus), bay mussels (M. edulis), and California sea mussels (Mytilus californianus), according to Quayle (1969b). In the fall of 1978, a severe outbreak of paralytic shellfish poisoning occurred as far south as Vashon Island in southern Puget Sound, Washington (Nishitani and Chew 1983). Shellfish in that area remained toxic for the unusually long time of 10 months, perhaps as a result of ingesting the cysts formed by P. catanella, which are 10 times more toxic than the dinoflagellate in the swimming stage (Magoon and Vining 1981). Winter storms may have kept cysts from settling as they normally do, allowing shellfish to ingest them. An alternative possibility is that enormous amounts of Protogonyaulax were carried into the area by water moving to southern Puget Sound (Nishitani and Chew 1983).

Pacific oysters lose their toxicity quickly, in a few weeks, compared to some shellfish species which may remain toxic for as long as a year. Oysters containing 176 mg of toxin were found to contain less than 32 mg after 4 weeks (Quayle 1969a).

Dupuy and Sparks (1968) found that Pacific oysters fed unialgal mass cultures of Gonyaulax washingtonensis showed no measurable uptake of toxin after 3 months. At Sequim Bay, Washington, toxin levels were 3 or 4 times lower in oysters than in California mussels (Dupuy and Sparks 1968).

The Health Services Division of the Washington State Department of Social and Health Services and local county health districts are responsible for testing shellfish semimonthly in both commercial and recreational beaches, and closing beaches for shellfish harvest when acceptable levels of toxin are exceeded (Nishitani and Chew 1983). In British Columbia, the Department of National Health and Welfare performs the testing for paralytic shellfish poison (Quayle 1969b). In Washington, beaches from Dungeness Spit to the Columbia River are closed annually from April 1 to October 31 due to relatively regular occurrences of paralytic shellfish poison (Nishitani and Chew 1983).

In bays with poor circulation in southern Puget Sound and southern Hood Canal in Washington, huge blooms of Ceratium fusus and Gymnodinium splendices can occur from June to December, with the heaviest concentration in August through October (Cardwell 1978; Magoon and Vining

1981). The Washington State Department of Fisheries has determined that blooms containing cells at a density of 10,000/ml are extremely toxic to oyster larvae. Since Pacific oysters spawn during the height of the bloom period, the occurrence of these blooms might explain some of the variability in yearly setting success of oysters (Magoon and Vining 1981).

ENVIRONMENTAL REQUIREMENTS

Temperature

Water temperature is critical to oyster growth and reproduction, and appears to be the main limiting factor in breeding success (Quayle 1969a). Temperature probably has an indirect effect on larvae by affecting the production of larval food (Quayle 1969a).

Pacific oysters live and grow in water with temperatures of 4 to 24°C, and are able to survive air temperatures as low as -4°C when exposed by the tide (Quayle 1969a). During feeding, water movement through the oyster is increased at higher temperatures; consequently, more food is filtered by the gills. Optimum temperature for water transport through adult oysters appears to be about 20°C (Quayle 1969a).

Willapa Bay, Washington, serves as an example of average water temperature conditions encountered by Pacific oysters. Winter water temperatures there range from 5 to 6°C. The water temperatures begin rising in March and reach an upper range of 12 to 15°C near mid-June (Korringa 1976). Increases in water temperature thereafter are extremely variable, and determine whether or not oysters in that area will successfully reproduce.

Oysters carry spawn during July and August, but do not release these gametes until the water temperature reaches 19°C (Magoon and Vining 1981). Larvae can survive temperatures below 15°C for a short time (Magoon and Vining 1981). Larvae can survive temperatures as high as 30°C. The larval period increases from 18 days at 72°F (22°C) to 30 days at 64°F (18°C) (Figure 6).

Westley (1968) found a positive relation between the depth of the warm water layer, the number of oyster larvae, and the intensity of oyster spatfall in Dabob Bay. High water temperatures and excellent larval retention of Dabob Bay, Washington, and Pendrell Sound, British Columbia, provide conditions conducive to the natural setting of Pacific oyster larvae (Korringa 1976). According to Chew (1983), larval setting increases as temperature increases between 15 and 30°C, but at 35°C there was a decline in setting (Figure 7). Commercial levels of spatfall are attributed to the regular summer occurrence of a warm water layer, up to 7 m deep, in which average temperatures exceed 20°C (Quayle 1969a). A strong thermocline occurs at a depth of about 4 m (12 ft) in Pendrell Sound (Quayle 1969a). Water above the thermocline is 21°C or more, while below this level the temperature decreases rapidly. Most Pacific

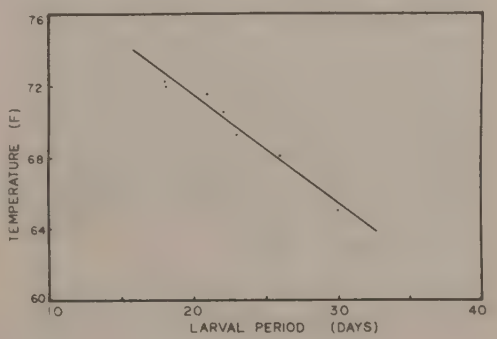


Figure 6. Duration of the larval period in Pacific oysters at various temperatures in British Columbia (after Quayle 1969a).

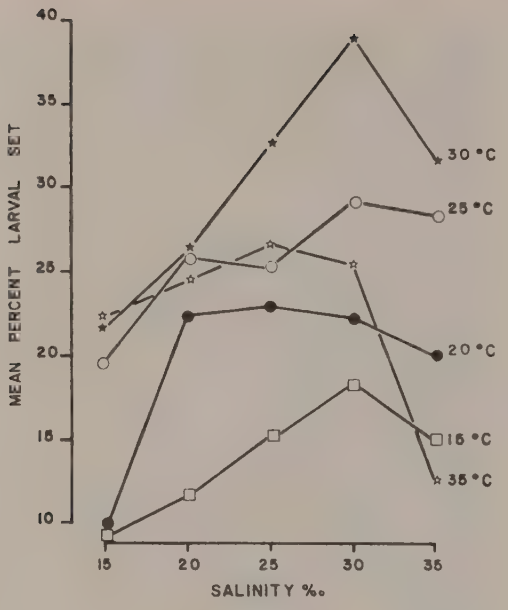


Figure 7. Remote setting of Pacific oyster eyed larvae at various salinities and temperatures in Washington (after Chew 1983).

oyster larvae do not descend below the thermocline (Quayle 1969a).

Oyster spat grown for 5 months in sea water warmed to 25°C experienced 28% mortality, compared to 18% for spat grown in 12°C water (Breese 1971). Diaz (1973) showed that large sudden increases in temperature of 10 to 20°C can have detrimental effects on growth rates, mortality, and setting rates of American oyster larvae. Initial growth of spat in heated water, however, was 14 times greater than spat grown in unheated water (Breese 1971).

Salinity

The inshore waters, bays, and estuaries where oysters are grown are subject to frequent seasonal changes in water salinity. Salinity is fairly uniform throughout the winter at about 28-29 ppt in the Strait of Georgia in British Columbia, but can change drastically in May as hillside runoff and river discharge add fresh water, thereby reducing the salinity during summer (Quayle 1969a).

Oysters are sensitive to changes in salinity, and respond to altered salinities by controlling the degree of shell opening (Galtsoff 1964). Consequently, salinity plays a major role in the volume of water transported, and hence the feeding of oysters. Optimum salinity for maximum water transport through the body of Crassostrea gigas is 25-35 ppt (Quayle 1969a). Pacific oysters become increasingly sensitive to salinities below 20 ppt. At 13 ppt, little water is pumped through the gills, even after several days of acclimation. Normal activity is quickly resumed after returning the oysters to higher salinities. Harmful effects are apparent in the gills at a salinity of 10.5 ppt, after which recovery in water of higher salinity is extremely slow (Hopkins 1936).

Laboratory studies indicated that setting of Pacific oyster larvae was unaffected by constant salinities between 16-34 ppt, but setting was retarded by rapidly fluctuating salinities (Lund 1971). Oyster larvae begin dying at a salinity of 10 ppt (Quayle 1969a). Chew (1983) indicated that as salinities increased from 15 ppt to 30 ppt remote setting of hatchery-reared larvae in artificial tanks increased, but at 35 ppt there was a decline in setting (Figure 7). Setting seems to increase with both increases in temperature and salinity (Figure 7). However, there is a dramatic decline in setting at the combined high temperature of 35°C and high salinity of 35 ppt (Figure 7). Optimum conditions for setting of eyed oyster larvae in the laboratory were observed at temperatures of about 30°C and salinities of about 30 ppt (Figure 7).

Salinity reduction can result in the elimination of predator species, such as the oyster drill and some fouling organisms, which are less euryhaline than oysters. The elimination of predators or fouling organisms results in a higher level of oyster productivity (Michael and Chew 1976).

Siltation and Substrate

Oysters are unable to move when faced with detrimental environmental conditions. Suspended bottom sediments can cause oysters to either stop feeding or expend considerable energy in separating mud and sand from edible particles (Quayle 1969a). Mortality of seed oysters planted in Ladysmith Harbour, British Columbia, reached 91% during the first year, with siltation as the causative factor (Quayle 1969a). Pereyra (1961, 1964) found siltation to cause mortalities as high as 22% in tray-reared oysters, while biweekly raising and resetting of baskets kept them relatively free from mud and probably helped reduce further mortalities.

Many oyster growers associate the yearly increase in oyster condition, known as fatness, with the increased turbidity of water occurring from March through November (Quayle 1969a). This turbidity is caused by several things, including quick blooms of microscopic marine organisms, silt, suspended detritus, or a varying mixture of all of these.

The effects of suspended sediments on Pacific oyster eggs and larvae still need to be investigated. The eggs of the Eastern oyster, C. virginica, experienced 20% mortality at silt concentrations of 0.25 g/l, and larval mortality of approximately 27% at silt concentrations of 0.50 g/l after 12 days of exposure (Davis and Hidu 1969).

Kennedy and Briesch (1981) reviewed several studies of dredging effects on Eastern oysters, and concluded that the response of oysters to dredging is affected by the type of sediment, the circulation of water in the area, the amount of sediment suspended and redistributed, and the topography of the oyster grounds. They suggested avoiding extensive dredging in oyster-producing areas during the oyster reproductive season, or during periods of elevated temperatures or lowered salinities that might increase the stress on oysters.

Water Circulation

Due to the sessile life style of the oyster, water circulation plays a paramount role in providing conditions for feeding and cleansing, as well as for successful reproduction and for the dispersal of oyster larvae. Westley (1964) found that areas <15 m deep with unstratified waters and having moderately rapid water exchange, were areas of good oyster condition. In addition, the depth of a warm (>17°C) water layer in late summer is just as important as the number of oyster larvae per sample in determining the density of setting oysters (Westley 1968). In Pendrell Sound, British Columbia, surface currents are weak, allowing only a small portion of the naturally produced oyster larvae to move out of the sound, thereby allowing heavy spat setting (Quayle 1969a). Greater flushing rates can cause unfavorable setting conditions for oyster larvae, by washing them away from preferred setting sites (Korringa 1976).

Excessive wave action, however, can tumble oysters about, knocking off their fragile shell edges (Quayle 1969a). High wave action also increases water turbidity by stirring up bottom sediments, causing silt accumulation over the oysters (Korringa 1976).

Pollution

A major long-term concern to the oyster industry in the Pacific Northwest is the present and potential future loss of water quality because of pollution. The various life stages of oysters (eggs, larvae, spat, and adults) have different levels of susceptibility to pollution (Woelke 1960b, 1960c; Quayle 1969a). Various types of pollutants can be concentrated in their body tissues, posing hazards to humans consuming affected oysters (Kennedy and Breisch 1981). Indirectly, pollution can result in loss of oyster food supply, poor growth, loss of larval vigor, increased susceptibility to disease, pests, or predation, contamination of settling surfaces, decreased fecundity, and reduced spawning (Quayle 1969a; Kennedy and Breisch 1981). The effects of pollutants can be exacerbated by other environmental stresses, such as changes in water temperature or salinity, even though oysters are tolerant of wide variations in both of these factors (Quayle 1969a).

Pacific oyster culture has been inhibited by the toxic or pathogenic pollution of waters by sewage, industrial waste, or pulp mill effluents (Gunn and Saxby 1982). Pollution results partly from the direct discharge of sewage into an area, or from the cumulative drainage from individual, improperly installed, or improperly functioning septic tanks (Quayle 1969a). Pollution can occur indirectly by runoff from surrounding agricultural land or urban areas, or through seepage from ground water following rainfall (Quayle 1969a; Beattie et al. 1982).

The embryonic and larval stages of an oyster are the most susceptible to poor water quality (Woelke 1960a, 1960b, 1960c; Beattie et al. 1982). Domestic sewage pollution can enhance algal blooms toxic to shellfish larvae, thus reducing or eliminating natural oyster reproduction (Beattie et al. 1982). One oyster hatchery in Washington was closed because of polluted bay water (Beattie et al. 1982).

Pierce County, one of the counties surrounding South Puget Sound, has placed restrictions on land use on bays where oysters are grown, regulating minimum lot size and septic system requirements in an attempt to reduce non-point source pollution (Beattie et al. 1982). Over 90% of Coos Bay, Oregon, has been barred from oyster production due to high content of coliform bacteria (Qualman 1982). Sewage pollution in British Columbia has resulted in the closure or restriction of a significant proportion of the potential oyster producing areas, including Boundary Bay and Ladysmith Harbour (Gunn and Saxby 1982). Various methods have been developed to purify oysters tainted by pollution (Quayle 1969a; Conte and Dupuy 1982).

The deterioration of oyster growing areas can also be caused by the forest industry, mainly as a consequence of pulp mill effluents and log processing procedures. Pulp mill effluent is known as sulphite waste liquor or kraft mill effluent depending upon the process used (Quayle 1969a), and both effluents consist of water, chemical waste, and some wood fiber. Upon discharge into the water, both chemical waste and fibers may affect oysters directly by causing mortality, reducing the growth rate, reducing fatness (thereby changing the condition index), and by altering the spawning cycle (Quayle 1969a). The measurement of these factors, while not particularly difficult in itself, becomes complex when effluent effects have to be separated from the wide variations that occur in the absence of pollution. Mortality is the simplest of these factors to measure, but only rarely are effluent concentrations high enough to cause significant mortality in the hardy Pacific oyster (Quayle 1969a). Concentrations of kraft mill effluent between 10 to

40 ppm exert a significant effect on the condition factor of Pacific oysters in British Columbia (Quayle 1969a). In Washington State, fresh sulphite waste liquor adversely affected 48-hr Pacific oyster larvae development at 2 ppm and it caused nearly 100% larval abnormalities at 18 ppm (Woelke 1960c). Indirectly, sulphite waste liquor can affect oysters by killing their food organisms. At 1,000 to 10,000 ppm, sulphite waste liquor is lethal to Monas spp., a flagellate protozoan that is an important oyster food (Woelke 1960a), and at concentrations as low as 2.5 ppm over several months time, it seemed to depress growth in Monas spp. Other flagellates, Cryptomonas and Isochrysis, and a diatom, Actinocyclus, that oyster feed upon were not greatly affected by concentrations of sulphite waste liquor as high as 304 ppm (Woelke 1960b).

In general, sulphite waste liquor was present at extremely high concentrations only in the vicinity of pulp mills, although some was found in nearly all areas of Puget Sound, Grays Harbor, and Port Angeles in Washington State (Woelke 1960a). A rapid decline occurred in open bays, especially in the summer (Woelke 1960b); this was related to the movement of the surface layer of water (Woelke 1960c).

Organic materials in pulp mill effluents require large amounts of oxygen for decomposition. A sufficient lowering of the oxygen concentration in sea water can virtually suffocate marine life (Quayle 1969a). In addition, large quantities of suspended wood fibre can clog the gills of filter-feeding animals such as oysters (Quayle 1960a).

Log booming sites often occur close to oyster beds. Debris, such as bark and wood chips, generally sink directly below the log booms, but some debris remains afloat long enough to be deposited in a mat on the surrounding bottom. Not only does this smother bottom-dwelling organisms by preventing adequate water circulation, but the decomposition of these materials depletes the oxygen supply and produces toxic hydrogen sulfide (Quayle 1969a). Log storage in Ladysmith Harbor, British Columbia, has apparently ended oyster production in that area (Gunn and Saxby 1982).

The effect of chemical pollution on C. gigas in the Pacific Northwest has not been thoroughly studied. However, Kennedy and Breisch (1981) reviewed the literature dealing with the chemical effects of pH, chlorine, heavy metal, petroleum hydrocarbons, and detergents on the Eastern oyster. Oysters near a former copper smelter in British Columbia contained 20,000 ppm of copper and 36,000 ppm of zinc, compared to average values of 600 ppm of copper and 10,000 ppm of zinc found in other areas (Quayle 1969a). The setting of Pacific oyster larvae under laboratory conditions was retarded by copper concentrations exceeding 0.1 mg/l (Lund 1971). Oysters have accumulated very low concentrations of arsenic leached from ships sprayed with an arsenic compound to prevent shipworm attack (Quayle 1969a).

Tests involving oyster larvae are used as a standard for the evaluation of environmental degradation (LeGore 1974). However, testing for contaminated oysters should be done by comprehensive monitoring, since isolated tests can result in a wide range of values due to tidal or seasonal fluctuations in pollutant levels (Morton and Shortridge 1975).

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16. Abstract (Limit: 200 words)

Species profiles are literature summaries of the taxonomy, morphology, range, life history, and environmental requirements of coastal aquatic species. They are designed to assist in environmental impact assessments. The Pacific oyster is found in the estuarine waters of California, Oregon, Washington, and British Columbia. It is sought both commercially and recreationally. Washington leads all other areas combined with a commercial production of 5.5 million pounds valued at $3.8 million. This is 26% of Washington State's total shellfish production value. These are very prolific animals, releasing up to 70 million eggs per year. Larvae are sensitive to a variety of environmental conditions, primarily temperature and salinity, and to pollutants including sulphite waste liquor. Growth is rapid and most noticeable in the third and fourth years. Along with other shellfish, Pacific oysters may accumulate toxin from Gonyaulax cantenella (responsible for paralytic shellfish poisoning), but they lose the toxin more rapidly than other shellfish. Optimum water temperature for adults is 20 °C and optimum salinities are above 20 ppt for adults. Ambient temperature is the single most critical item to breeding success in the Pacific Northwest.

17. Document Analysis a. Descriptors

Temperature
Estuaries
Oysters
Salinity
Feeding habits
Growth
Sediments
Life cycles
Suspended sediments
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b. Identifiers/Open-Ended Terms

Pacific Oyster
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